NORMAL CONDUCTING RF CAVITY FOR MICE*

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Abstract

Normal conducting RF cavities must be used for the cooling section of the international **M**uon **I**onization **C**ooling **E**xperiment (MICE), currently under construction at **R**utherford **A**ppleton **L**aboratory (RAL) in the UK. Eight 201-MHz cavities are needed for the MICE cooling section; fabrication of the first five cavities is complete. We report the cavity fabrication status including cavity design, fabrication techniques and preliminary low power RF measurements.

INTRODUCTION

The **N**eutrino **F**actory (NF) and **M**uon **C**ollider (MC) offer great potential physics opportunities, but both are difficult to build. Intense muon beams are produced with very large six-dimensional emittance and have short lifetime (~ 2.2 μs at rest). One of the main challenges is how to effectively manipulate the intense muon beams, in particular how to reduce their transverse emittance, — i.e., beam cooling. Ionization cooling is considered to be the only practical cooling scheme for muons. However, as yet no one has demonstrated muon ionization cooling experimentally. MICE is such a demonstration experiment, in which a section of an actual ionization cooling channel (based on the US Feasibility Study-II design) will be built and tested. The experiment is currently under construction at the Rutherford Appleton Laboratory (RAL) in the UK [1]. The experiment includes a dedicated beam line to generate a range of input muon beam emittance and momentum, with time-of-flight and Cherenkov detectors to ensure beam purity. The emittance of the incoming muon beam is measured in an upstream magnetic spectrometer with a scintillating fiber tracker. A cooling section will then follow, consisting of three liquid hydrogen absorbers enclosed in superconducting focusing coils and two RF-Coupling Coil Modules; each of these "RFCC" modules comprises four 201-MHz normal conducting RF cavities surrounded by a superconducting solenoid magnet. Muon beams lose energy in the liquid hydrogen absorber and regain the lost longitudinal energy from the RF cavities, thereby resulting in a net reduction of transverse emittance. A second, downstream spectrometer identical to the first one and an electron-muon identification system provide a measurement of the outgoing muon-beam emittance. Figure 1 shows an engineering model of the MICE experiment setup.

Very high gradient normal conducting RF cavities are required for muon ionization cooling, as the muons decay and are confined in strong magnetic fields.

Hardware research & development for muon ionization cooling has been the main focus of the MuCool program under the US NFMCC (Neutrino Factory and Muon Collider Collaboration). MICE RF cavity design is based on the successful RF cavity built for the MuCool program.

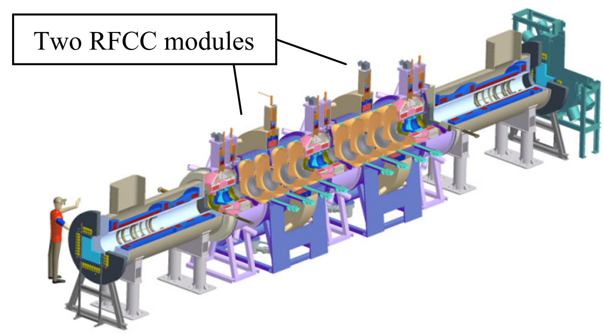

Figure 1: MICE cooling channel: three AFC (Absorber and Focusing Coil) and two RFCC (RF cavity and Coupling Coil) modules.

MICE RF cavities will be operated at a 1-Hz repetition rate, with 1-ms pulse length, at a modest gradient of 8 MV/m, limited by available RF power.

This paper reports recent progress on the fabrication of MICE RF cavities and low power measurements.

201-MHZ CAVITY FOR MICE

The cavity design, fabrication techniques and post-processing are based on the successful prototype cavity for the US MuCool program [2,3]. Unlike the prototype cavity, MICE cavities will be installed in a vacuum vessel such that there is differential pressure on neither the cavity body nor the thin beryllium windows. Nevertheless, integration of the cavity with its RF tuners, support structure and superconducting coupling coil within the vacuum vessel is a challenging task due to tight spacing [4].

Significant progress has been made on RF cavity fabrication since 2009. The first five MICE cavities are complete; the next five will be ready soon. Preliminary low power RF measurements have been conducted.

Cavity Design

The MICE cavity design features a round pillbox profile (similar to that of the MuCool prototype cavity) with the ratio of peak surface electric field to the accelerating field on axis being almost one. In addition, the conventional open beam irises are terminated by curved 0.38-mm thick, 42-cm diameter beryllium foils

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(windows). Muon beams penetrate the beryllium foils with very little scattering. The cavity shunt impedance is increased by nearly a factor of two by this termination. The main design parameters of the MICE RF cavities are listed in Table 1. For the nominal neutrino factory design, the cavity gradient is specified as ~ 16+ MV/m, requiring up to 5 MW peak RF power for each cavity.

Table 1: Main design parameters of the 201-MHz cavity

Parameter	Value	Unit
Frequency	201.25	MHz
Shunt impedance	22	MΩ/m
Cavity diameter	121.7	cm
Beam iris (diameter)	42.0	cm
Cavity gap (length)	42.0	cm
Quality factor Q	53,500	

The (2D) SUPERFISH and (3D) CST MWS codes have been used for the RF design of the cavity. The ANSYS FEA code with multi-physics modules has been used to simulate electromagnetic fields, and to study thermal and mechanical design issues with thin beryllium windows.

Cavity Fabrication

Like the MuCool prototype cavity, each MICE cavity is formed from two half shells. Each half shell is spun from ~ 6-mm flat copper sheet against a machined mold . The mold is made from Bakelite.

The cavity body spinning was conducted by the ACME Company in Minneapolis, MN. The copper sheets were pre- and post-polished before and after spinning. Hand polishing was applied to areas with visible scratches. The spun half shells were shipped to Applied Fusion in Hayward, CA, where e-beam welding and port extruding were carried out. Figure 2 shows a cavity with two spun half shells being joined by e-beam welding.

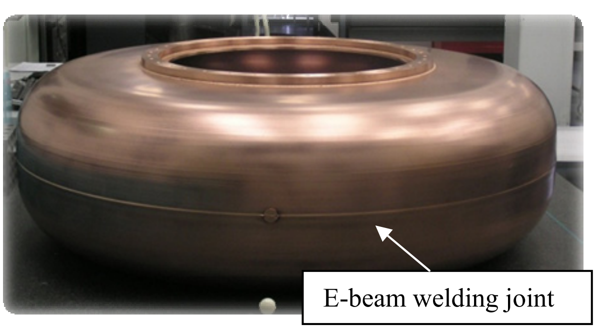

Figure 2: MICE cavity: two half shells are joined by e-beam welding to form the cavity.

There are four ports on the cavity equator for RF power couplers, vacuum, and RF probes, respectively. These ports are formed by pulling a die through a pilot hole cut across the equator weld: extruding, a technique developed and successfully used for the MuCool prototype cavity.

Figure 3: There are four ports on the cavity equator. They are made by extruding: a pilot hole (upper photo) is first cut, followed by pulling a die through the hole. Lower photo shows the finished ports.

Water cooling tubes are TIG brazed external to the cavity body. Special attention is required to ensure that good thermal contact to the cavity is achieved and minimum cavity deformation introduced during the brazing process. Figure 4 shows the finished cavity with water cooling tubes attached.

Figure 4: Finished MICE cavity with water cooling tubes TIG brazed external to the cavity body.

The first five cavities are complete and were shipped to LBNL in December 2009. An additional five cavities are now in production at Applied Fusion Corp. We have begun physical and RF measurements of the first five cavities.

Cavity Measurements

Both physical and RF measurements of the first five cavities have been conducted at LBNL. Special probes were purchased to measure the interior profile of the cavity. Four CMM scans (90 degrees apart) are performed for each cavity with each scan having ~ 1800 points. Figure 5 shows the CMM scan setup. The CMM data will be used to evaluate the as-built cavity with simulation tools.

Figure 5: Physical measurements: CMM scan setup of MICE cavity at LBNL.

Four MICE cavities have been measured with low RF power using a Network Analyzer. The measurements agree well with simulation. Curved beryllium windows are bolted onto the cavity irises. Figure 6 (left) shows a thin curved beryllium window installed on the cavity.

Figure 6: Beryllium window installation and (left) installed window on MICE cavity.

The same two beryllium windows were used to conduct low power RF measurements for each cavity. Due to variations in the fabrication process the two window profiles are slightly different. Cavity frequency and Q values were measured via both S_{11} (reflection) and S_{21} (transmission) with various window configurations. Measurement results are summarized in Table 2 below.

The measured frequency in Table 2 is referred as cavity body frequency, equivalent to that of the cavity with flat windows, as shown in Figure 7. The measured frequency of Cavity #5 (spare cavity) is higher than that of the other cavities because no water cooling tubes were brazed to its cavity body.

As each curved beryllium window introduces a different perturbation on the cavity body frequency, we

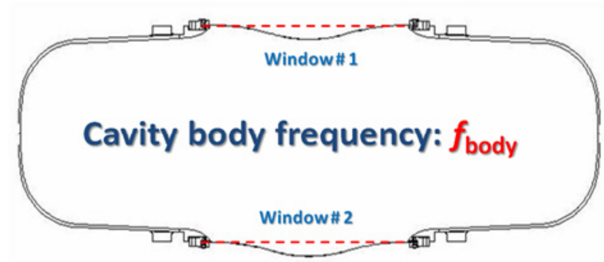

Figure 7: The measured frequency is referred to as cavity body frequency with flat windows as shown. The cavity frequency with curved windows is considered to be a perturbation on the cavity body frequency.

Table 2: Measured cavity body frequencies and Q

	Frequency (MHz)	Measured Q
Cavity #1	201.084	44,600
Cavity #3	201.247	44,000
Cavity #4	200.740	43,600
Cavity #5	{201.707}	{44,000}

can use the beryllium windows to our advantage, to provide an additional tuning knob for cavity frequency. This requires that each beryllium window be installed on and measured with a pre-measured cavity. Our measurements have indicated that the cavity frequency variation is within ± 400 kHz, as predicted given the fabrication techniques and simulations. Once all ten cavities are measured, we plan to tune the cavity frequency to an average (center) frequency by physically deforming the cavity body. Dynamic tuning of the cavity during commissioning and operation will be realized by mechanical tuners installed on the cavity bodyies [2]. These tuners can provide a tuning range of ± 230 kHz.

SUMMARY

Fabrication of the first five MICE cavities is complete. Preliminary low power RF measurements agree well with design. The next five cavities are in fabrication now. Other auxiliary cavity components (beryllium windows, RF power couplers, tuners and supporting structures and vacuum vessel) are either in the final design phase or in fabrication.

REFERENCES

[1] Latest information on MICE and the collaboration can be found at http://www.mice.iit.edu

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